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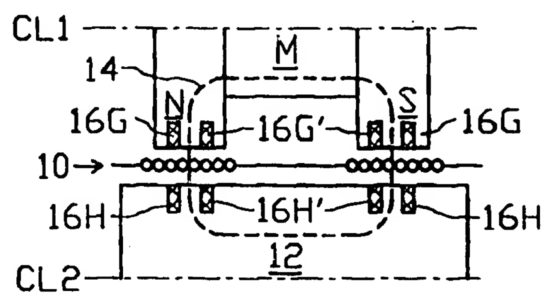
(54) Title: SHORTING RINGS IN DUAL-COIL DUAL-GAP LOUDSPEAKER DRIVERS

(57) Abstract

Loudspeakers and other transducers of the dual-voice-coil/dual-magnetic-gap type can be improved by the addition of one or more annular shorting rings (16A-16S) strategically located in the vicinity of the two magnetic gaps. The shorting rings have no effect on a steady state magnetic field but act in opposition to any change in flux density or any displacement of the flux lines such as those that occur under the loading imposed when the voice coils (10A, 10B) are driven hard with audio frequency current. Thus a plurality of rings can be strategically deployed at different locations so as to optimally suppress both even and odd order harmonic distortion and to reduce the voice coil inductance.



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PATENT APPLICATION for
SHORTING RINGS IN DUAL-COIL DUAL-GAP LOUDSPEAKER DRIVERS

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Ralph E. Hyde
Alex Salvatti

PRIORITY

Benefit is claimed under 35 U.S.C. § 119(e) of pending provisional application 60/078,623 filed 03/19/98.

FIELD OF THE INVENTION

The present invention relates to the field of electromagnetic transducers and actuators, and more particularly it relates to improvements in loudspeaker drivers of the type having dual voice coils axially located in corresponding dual annular magnetic air gaps on a common axis.

BACKGROUND OF THE INVENTION

In addressing fundamental design issues of dual-voice-coil dual-magnetic-gap loudspeaker drivers as related to conventional single-voice-coil drivers, the present inventors have found that the dual-voice-coil dual-gap type offers advantages with regard to linearity, efficiency, available voice coil excursion, power compression, heat dissipation and maximum sound pressure output capability. Furthermore they have found that certain benefits of the dual-coil dual-gap approach can be further enhanced by introducing shorting rings in the region of the two magnetic gaps near the voice coils.

DISCUSSION OF RELATED KNOWN ART

Japanese patent 61-137496 to Okada introduces a conductive annular plate in a speaker magnet structure to

prevent burning of a voice coil and to prevent an eddy current giving adverse influences to a voice coil current.

U.S. patent 5,381,483 to Grau discloses a minimal inductance electrodynamic transducer having ferromagnetic shunting rings coated with a highly conductive material to increase the induced current carrying capacity of the transducer.

U.S. patent 3,830,986 to Yamamuro discloses a MAGNETIC CIRCUIT FOR AN ELECTRO-ACOUSTIC CONVERTER having an air gap formed of a magnetic material laminated with a conductive layer for acting as shorting rings to decrease the inductance of the voice coil.

Japanese patent WO 81/02501 discloses a MAGNETIC CIRCUIT FOR AN ELECTRO-MECHANICAL TRANSDUCER OF A DYNAMIC ELECTRICITY TYPE wherein compensating coils or conductors within the magnetic gaps are supplied with signal current to prevent disturbances in the magnetic field.

Japanese patent 198208 discloses an ELECTROMAGNETIC CONVERTER wherein a magnetic ring is located in the air gap so that it can be moved axially between a circumferential yoke and a center yoke to provide good conversion efficiency by using a hollow disk permanent magnet that is magnetized in different poles at the center and external circumference.

U.S. patent 3,783,311 to Sato et al discloses a MAGNETIC DEVICE FOR USE IN ACOUSTIC APPARATUS wherein a metallic member in a voice coil gap permits the lines of magnetic force to move substantially in one direction only, for distortion reduction.

Soviet Union patent 587645/SU197801 to Rotshtein for an electromagnetic loudspeaker magnetic circuit disclose a magnetic shunt of soft magnetic material placed over a core pole piece to increase acoustic pressure by decreasing magnetic resistance.

The foregoing patents are confined to conventional loudspeaker driver/actuator construction having only a single gap and a single voice coil.

Patents that disclose dual voice coil dual magnetic gap drivers/actuators include U.S. patents 4,612,592 to Frandsen, 5,231,336 to Van Namen, and French patent 1,180,456 to Kritter; however these do not disclose the use of shorting rings.

U.S. patent 4,914,707 to Kato et al for a BALANCE VEHICULAR SPEAKER SYSTEM suggests attaching a shorting ring to a coil of a dual coil dual gap front speaker in a vehicle to decrease the high frequency impedance as an alternative to connecting a resistor in series with a rear speaker, for purposes of making the impedance of the rear speaker higher than that of the front one.

OBJECTS OF THE INVENTION

It is a primary object of the present invention to provide improvements in a dual-voice-coil/dual-magnetic-gap type transducer that will reduce harmonic distortion in the acoustic output.

It is a further object of the present invention to implement the aforementioned improvements in a manner that will reduce even order harmonic distortion including particularly second harmonic distortion.

It is a still further object of the present invention to implement the aforementioned improvements in a manner that will reduce odd order distortion including particularly third harmonic distortion.

SUMMARY OF THE INVENTION

The above-mentioned objects and have been accomplished and the advantages have been realized by the present invention as applied as an improvement to loudspeakers and other transducers of the

dual-voice-coil/dual-magnetic-gap type by the addition of one or more shorting rings of high conductivity metal strategically located in the vicinity of the two magnetic gaps close to the voice coils.

The shorting rings have no effect on a steady state magnetic field but act in opposition to any change in flux density or any displacement of the flux lines such as those that occur under the loading imposed when the voice coils are driven hard with audio frequency current. The location of the shorting rings determines their effect: location close to a voice coil reduces the voice coil inductance, location entirely within the magnetic flux loop centerline favors reduction of second harmonic and higher order even harmonic distortion, a centered location on the flux loop centerline, i.e. centered in the magnetic gap, favors reduction of third harmonic and higher odd order harmonic distortion, while location outside the flux loop centerline but near the voice coil acts generally to reduce harmonic distortion. Thus a plurality of rings can be differently located so as to optimally suppress both even and odd order harmonic distortion and reduce the voice coil inductance.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and further objects, features and advantages of the present invention will be more fully understood from the following description taken with the accompanying drawings in which:

FIGs. 1-3 show shorting rings located inside the flux loop for reducing even order harmonic distortion.

FIGs. 4-5 show shorting rings located outside the flux loop.

FIGs. 6-7 show at least two shorting rings located inside the flux loop and at least two located outside the flux loop.

FIGs. 8-10 show shorting rings centered on the flux loop for best suppression of odd order harmonics.

FIGs. 11 and 12 show shorting rings in tubular form extending through both gaps.

DETAILED DESCRIPTION

FIGs. 1-12 are basic functional representations of a dualgap dual-voice-coil loudspeaker driver, shown in half crosssection with a voice coil assembly 10 carrying voice coils 10A and 10B suspended in a pair of magnetized air gaps formed from a permanent magnet M disposed between a first steel pole piece N at the north pole of magnet M and a second steel pole S at the south pole of magnet M, and a yoke 12 which is made of magnetic material and which can be considered to define, in effect, a pair of pole pieces that would substantially mirror the articulated pole pieces N and S of magnet M and thus form the two magnetic gaps.

The magnetic system of the foregoing structure sets up a magnetic flux loop in the path shown as a dashed line, i.e. flux loop center line 14, which is typically centered within each magnetic gap and within each voice coil 10A and 10B.

Voice coil assembly 10 is constrained by well known spring suspension diaphragm structure (not shown) so that it travels axially, typically driving a conventional speaker cone diaphragm (not shown) in response to AC (alternating current) applied to coils 10A and 10B, in accordance with the well known Right Hand Rule of

electro-magnetic mechanics and in the general manner of loudspeakers, the two coils being phase-connected accordingly.

The half cross-section shown in FIGs. 1-12 represents a coaxial loudspeaker motor structure that can have either of two basic configurations that are inverse of each other:

(1) coaxial about center line CL1 with magnet M inside of the annular voice coil assembly 10 so that magnet M with pole pieces N and S are cylindrical in shape while yoke 12 is tubular in shape surrounding voice coil assembly 10, or

(2) coaxial about center line CL2 with a cylindrical yoke 12 inside voice coil assembly 10, and magnet M and pole pieces N and S being annular in shape, surrounding voice coil assembly 10.

A common inherent shortcoming in loudspeakers is that the magnetic flux in the region of the voice coil(s) is subject to pattern deformation or modulation as a reaction to drive current in the voice coil(s); this in turn can distort the acoustic output as well as increase the inductance of the coil winding(s), altering the frequency response.

As indicated in the above discussion of related known art, it has been found that the introduction of shorting/shunting rings of highly conductive metal such as copper in the vicinity of the magnetic air gap of conventional single coil drivers can provide benefits by acting to stabilize the magnetic flux against such perturbation from modulation due to voice coil current. Such shorting rings have no effect on the flux pattern as long as it remains constant and stationary, however the rings react with an internal flow of current that opposes any change in the flux pattern such as would be caused by the drive current in the voice coils, thus the rings can

substantially reduce distortion in the acoustic output. Also a shorting ring located near a voice coil tends to reduce the inductance of the voice coil.

The present inventors, in research directed to improvements in dual-gap dual-coil transducer drivers, have identified key locations and configurations for such shorting rings, particularly with regard to distortion reduction, and have developed such locations and configurations for reducing second and/or third harmonic distortion selectively.

FIGs. 1-3 show locations of tubular-shaped shorting rings Shat are located within the flux loop as defined by its center line 14 and that therefore act in a manner to reduce even order harmonic distortion including particularly second harmonic distortion in accordance with the present invention.

In FIG. 1, the tubular shorting ring 16A is located adjacent to permanent magnet M, essentially extending between the two pole pieces N and S in a location adjacent to voice coil assembly 10 and entirely within the flux loop defined by center line 14. In FIG. 2, the tubular shorting ring 16B is embedded in a recessed region of yoke 12, essentially extends between the two yoke pole pieces in a location adjacent to voice coil assembly 10 and entirely within the flux loop defined by center line 14. In FIG. 3, two rings are incorporated in a driver unit: ring 16A, as in FIG. 1 and ring 16B, as in FIG. 2; since both rings are located within the flux loop defined by center line 14, the even order harmonic distortion suppression is greater than in either FIG. 1 or FIG. 2.

FIGs. 4 and 5 show locations of annular shorting rings 16D and 16E configured as disks that have an edge positioned close to the voice coils of assembly 10 and that, being located outside the flux loop center line 14,

act generally to reduce harmonic distortion and reduce voice coil inductance in accordance with the present invention.

In FIG. 4 a first pair of shorting rings 16C are located on the outer surfaces of pole pieces N and S respectively and a second pair of shorting rings 16D are located on each end of yoke 12, all having an edge in close proximity to the voice coils of assembly 10. The shorting rings 16C and 16D are shaped as annular disks, i.e. flat washers, however, depending on the configuration, i.e. whether CL1 or CL2 is the central axis, the pair of shorting rings that are centered on the axis need not have a central hole and thus could be shaped simply as circular disks.

In FIG. 5, two shorting rings 16E are fitted in the outer corners of yoke 12, in close proximity to the voice coils of assembly 10, but outside the flux loop as defined by center line 14.

FIGs. 6 and 7 show configurations with shorting ring locations near the voice coils both inside and outside the flux loop as defined by center line 14, thus acting mainly to suppress second harmonics and higher order even harmonics and to reduce voice coil inductance.

In FIG. 6, two shorting rings 16F' are located in the inner corners of each of the magnet pole pieces N and S, within the flux loop and acting mainly on even order harmonics, while two rings 16F are located in the outer corners of the magnet pole pieces N and S and two rings 16E are located in the outer corners of the yoke, as in FIG. 5, these four rings, being located outside the flux loop but close to the voice coils of assembly 10, will thus acting generally to reduce harmonic distortion and reduce the inductance of the voice coils.

In FIG. 7, a total of eight rings are deployed; a pair of shorting rings 16G and 16G' embedded in each of

the pole pieces N and S as shown, and two corresponding pairs of shorting rings 16H and 16H' embedded in corresponding locations in yoke 12, so that four of the rings are inside the flux loop and the other four are outside the flux loop.

FIGs. 8-10 show shorting rings located substantially centered on the flux loop center line 14: this is the optimal location for suppression of odd order harmonics, particularly third harmonics.

In FIG. 8, shorting rings 16J and 16K are embedded in a center location, one each in all four pole pieces defining the two magnetic gaps, substantially centered on the flux loop center line 14.

In FIG. 9, the total faces of poles N and S are configured with laminated shorting ring structures 16L, and corresponding laminated shorting ring structures 16H are embedded in the upper pole piece regions of yoke 12 adjacent the voice coils as shown. These laminated shorting ring structures 16L and 16H consist of sheets of electrically conductive metal (typically copper or aluminum) interleaved with magnetic grade steel laminations. This approach represents the closest possible approach to ideal conditions for reducing acoustic distortion, both second and third harmonics and their higher order multiples, and reducing voice coil inductance, since the laminated shorting rings act in the manner of a large number of individual shorting rings, some located inside the flux loop, some centered thereon and some located outside the flux loop, but all located close to the voice coils. This type of shorting ring is particularly beneficial at higher audio frequencies.

FIG. 10 depicts essentially an unlaminated version of FIG. 9: lower faces of pole pieces N and S are fitted with shorting rings 16P of tubular shape, and yoke 12 is fitted with embedded shorting rings 16Q of tubular shape,

somewhat longer than rings 16P and thus extending inwardly from the outer corners past the voice coils of assembly 10, acting to lower the voice coil inductance as well as to reduce harmonic distortion optimally.

In FIG. 11, a single tubular shorting ring 16R extending full length of the magnet assembly including a surface layer added onto the faces of pole pieces N and S close to the voice coils, thus acting to reduce voice coil inductance as well as to reduce harmonic distortion.

FIG. 12 depicts essentially a version of FIG. 11 with the tubular shorting ring 16S deployed as a surface layer extending full length along the upper surface of yoke 12 including its pole regions, close to the voice coils, thus providing further reduction in voice coil inductance.

Alternative viable combinations of FIGs. 10-12 include: ring 16R (FIG. 11) deployed in place of rings 16P in FIG. 10; ring 16S (FIG. 12) deployed in place of rings 16Q in FIG. 10; ring 16S (Fig. 12) deployed in yoke 12 in FIG. 11.

In the various shorting ring patterns, suppression of harmonic distortion generally becomes more effective as the ring(s) are made more massive and/or numerous.

Shorting rings are most effective in reducing harmonic distortion in the audio frequency range 200 to 2,000 Hertz.

Typical results in distortion reduction were measured as follows:

	200 Hz	500 Hz	1 kHz
Frequency:	200 Hz	500 Hz	1 kHz
1. Ring configuration: FIG. 1 and FIG. 5 combined;			
2nd harmonic reduction:	5 dB	6 dB	14 dB

3rd harmonic reduction: 11 dB 10 dB 2 dB

2. Ring configuration: FIG. 5;
2nd harmonic reduction: no appreciable reduction
3rd harmonic reduction: 9 dB 4 dB 2 dB

This invention may be embodied and practiced in other specific forms without departing from the spirit and essential characteristics thereof. The present embodiments therefore are considered in all respects as illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description. All variations, substitutions, and changes that come within the meaning and range of equivalency of the claims therefore are intended to be embraced therein.

What is claimed is:

1. An improved loudspeaker driver structure for driving a vibratable diaphragm to produce sound, comprising:

first and second similar annular voice coils, located spaced apart end-to-end on a tubular voice coil form as part of a coaxial voice coil assembly that is disposed about a central axis, drivingly coupled to the diaphragm and resiliently constrained to be vibratable only in a longitudinal direction of the axis;

first and second annular magnetic pole pieces, configured and arranged as an interfacing pair forming a first annular magnetic gap traversing a predetermined annular portion of said first voice coil;

third and fourth annular magnetic pole pieces, configured and arranged as an interfacing pair forming a second annular magnetic gap traversing a predetermined annular portion of said second voice coil;

a permanent magnet having a first magnetic pole directed to to said first pole piece, and having a second magnetic pole directed to said third pole piece;

a magnetic yoke having a first end directed to said second pole piece and having a second end directed to said fourth pole piece thus providing a main magnetic path around a flux loop encompassing, in series: (a) said magnet, (b) said first pole piece constituting a first magnet pole piece, (c) the first magnetic gap, traversing said first voice coil, (d) said second pole piece constituting a first yoke pole piece, (e) said yoke, (f) said fourth pole piece constituting a second yoke pole piece, (g) the second magnetic gap, traversing said second voice coil, and (h) said third pole pieces, constituting the second magnet pole piece, completing the flux loop; and

at least one annular shorting ring made from highly conductive metal, disposed coaxially and located in

coupled relationship with the flux loop, configured and arranged to act as a short-circuited winding turn that opposes any change in strength of the flux loop and opposes any displacement thereof so that whenever said voice coils are energized with audio frequency current so as to cause the coil form to vibrate the diaphragm, said ring is caused to react in a manner to reduce harmonic distortion in acoustic output of said loudspeaker.

2. The improved loudspeaker driver structure as defined in claim 1 wherein said at least one annular shorting ring is disposed entirely within the magnetic flux loop as defined by a center line thereof, so as to act in a manner to particularly reduce even order harmonic distortion in the acoustic output.

3. The improved loudspeaker driver structure as defined in claim 2 comprising a single annular shorting ring, disposed adjacent to said magnet, between said magnet and the voice coil form, and extending substantially between the two magnet pole pieces.

4. The improved loudspeaker driver structure as defined in claim 2 comprising:

a single annular shorting ring disposed adjacent to said yoke, between said yoke and the voice coil form, and extending substantially between the two yoke pole pieces.

5. The improved loudspeaker driver structure as defined in claim 2 comprising:

a first annular shorting ring, disposed adjacent to said magnet, between said magnet and the voice coil form, and extending substantially between the two magnet pole pieces; and

a second annular shorting ring, disposed adjacent to said yoke, between said yoke and the voice coil form, and extending substantially between the yoke pole pieces.

6. The improved loudspeaker driver structure as defined in claim 1 comprising at least two said annular rings, each disposed in a substantially symmetric manner about the center line of the magnetic flux loop, so as to particularly reduce odd order harmonic distortion in the acoustic output.

7. The improved loudspeaker driver structure as defined in claim 6 wherein each of said annular shorting rings is configured in tubular form constituting, in effect, a surface layer on a corresponding one of said four pole pieces.

8. The improved loudspeaker driver structure as defined in claim 6 wherein each of said annular shorting rings is embedded in a central surface region of a corresponding one of said four pole pieces.

9. The improved loudspeaker driver structure as defined in claim 2 wherein at least one of said annular shorting rings is fabricated from a stack of individually isolated laminations of magnetic grade steel.

10. The improved loudspeaker driver structure as defined in claim 1 wherein at least one said annular shorting ring is configured in a tubular form extending across both of a pair of said pole pieces so as to constitute, in effect, a surface layer on each pole piece.

11. The improved loudspeaker driver structure as defined in claim 1 comprising:

at least one annular shorting ring disposed entirely within the magnetic flux loop as defined by the center line thereof, so as to act in a manner to particularly reduce even order harmonic distortion in the acoustic output; and

at least one annular shorting ring disposed outside the magnetic flux loop as defined by the center line thereof.

12. The improved loudspeaker driver structure as defined in claim 11 comprising eight annular shorting rings of which two are disposed in each of said pole pieces in opposite regions thereof such that four outermost of the shorting rings are disposed outside the magnetic flux loop as defined by the center line thereof, and the four innermost of the shorting rings are disposed within the flux loop as defined by the center line thereof.

13. The improved loudspeaker driver structure as defined in claim 1 wherein said at least one annular shorting ring is disposed substantially outside the magnetic flux loop as defined by the center line thereof.

14. The improved loudspeaker driver structure as defined in claim 13, comprising two annular rings, each made to have a narrow width that is less than half the voice coil length, and each disposed outside the flux loop as defined by the center line thereof, as follows:

a first annular shorting ring disposed along an outermost edge of the first magnet pole piece, adjacent said voice coil form; and

a second annular shorting ring disposed along an outermost edge of the second magnet pole piece, adjacent said voice coil form.

15. The improved loudspeaker driver structure as defined in claim 13, comprising two annular rings, each made to have a narrow width that is less than half the voice coil length, and each disposed outside the flux loop as follows:

a first annular shorting ring disposed along an outermost edge of the first yoke pole piece, adjacent said voice coil form; and

a second annular shorting ring disposed along an outermost edge of the second yoke pole piece, adjacent said voice coil form.

16. The improved loudspeaker driver structure as defined in claim 13 comprising four annular rings, each disposed outside the flux loop as follows:

a first annular shorting ring disposed along an outermost end of the first magnet pole piece, extending close to said voice coil form;

a second annular shorting ring disposed along an outermost end of the second magnet pole piece, extending close to said voice coil form;

a third annular shorting ring disposed along an outermost end of the first yoke pole piece, extending close to said voice coil form; and

a fourth annular shorting ring disposed along an outermost end of the second yoke pole piece, extending close to said voice coil form.

17. An improvement in an audio loudspeaker driver structure having two mechanically coupled similar annular voice coils, located coaxially relative to a common axis on a common tubular voice coil form, each voice coil being disposed in a corresponding magnetic field set up in a gap formed between annular pole pieces disposed inside and outside the voice coil from a permanent magnet providing a magnetic flux loop that traverses each gap in series with a yoke magnetically linking two of the pole pieces, the voice coils being suspended with freedom to vibrate in a direction along the axis in response to alternating electric current made to flow in the voice coils, said improvement comprising:

at least one annular ring of highly conductive metal disposed in a region adjacent the voice coils, made and arranged to oppose any change in intensity or location of the magnetic flux from the permanent magnet and thus reduce distortion in acoustic output of the loudspeaker.

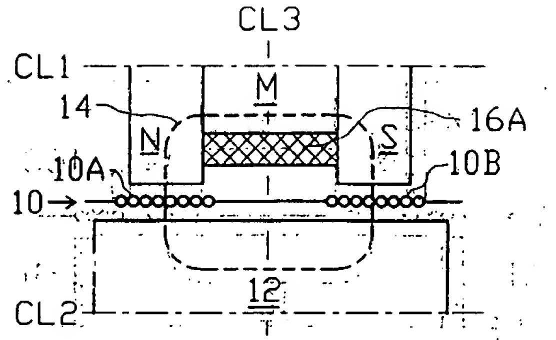

FIG. 1

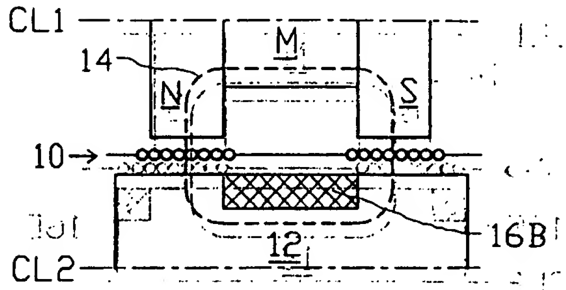

FIG. 2

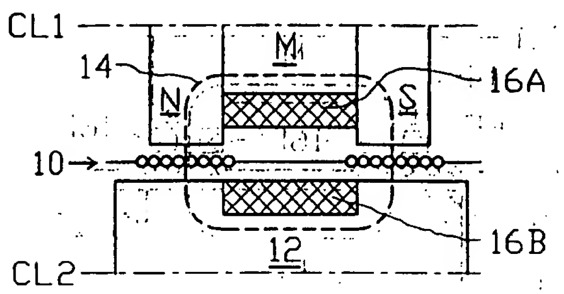

FIG. 3

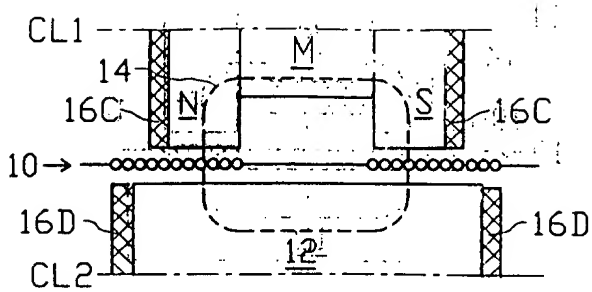

FIG. 4

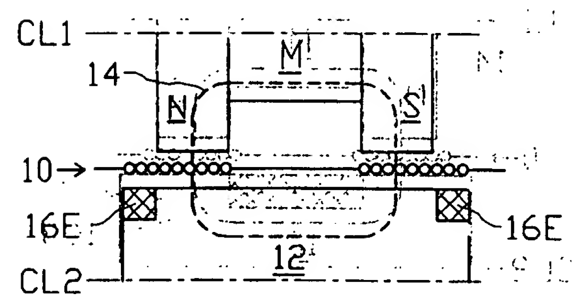

FIG. 5

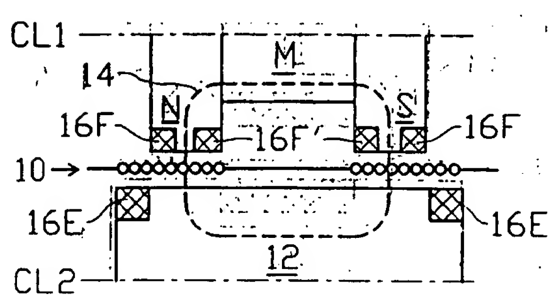

FIG. 6

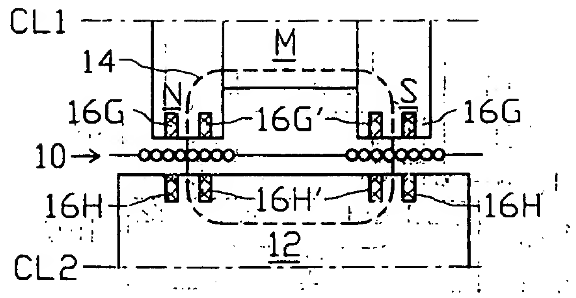

FIG. 7

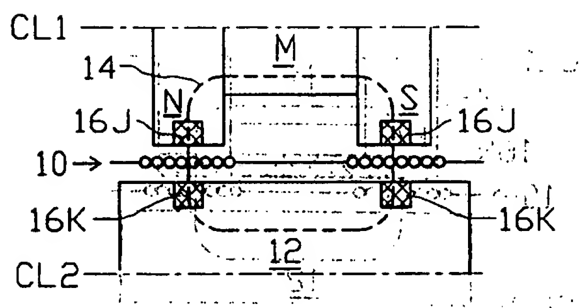

FIG. 8

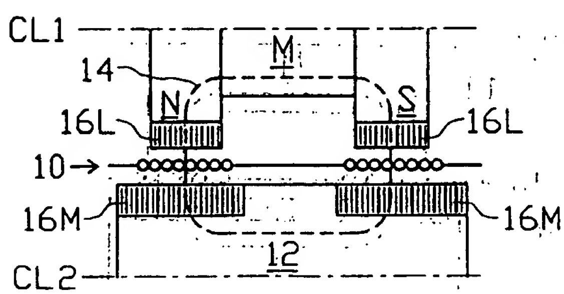

FIG. 9

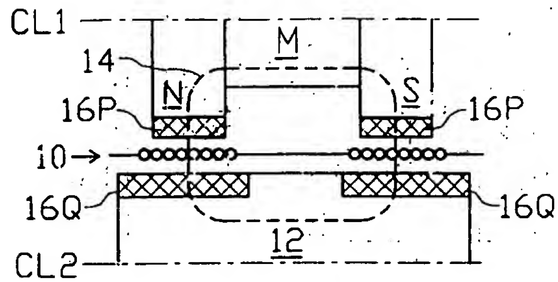

FIG. 10

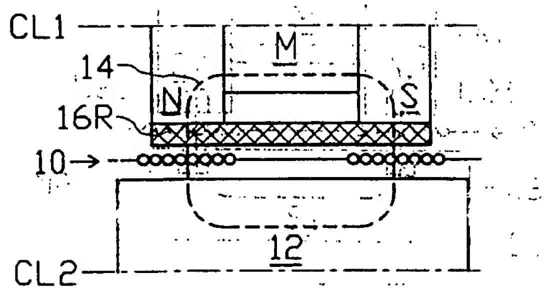

FIG. 11

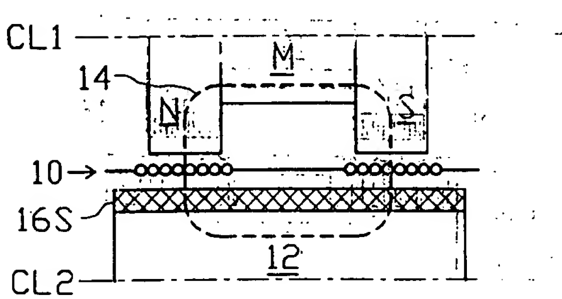

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/06084

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04R 25/00
US CL :381/412, 414
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 381/412, 414, 419

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: shorting ring# or short-circuit ring#

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,914,707 A (KATO) 03 April 1990, see Fig. 7	1-10 and 17.
Y	US 5,381,483 A (GRAU) 10 January 1995, see Fig. 1.	1-2, 4-10 and 17.
Y	US 3,881,074 A (KAWAMURA) 29 April 1975, see Figs. 1 and 2.	1-3, 5 and 11-16.
Y	US 3,632,904 A (MAUZ) 04 January 1972, see Fig. 1.	1-2, 4-10 and 17.
Y	US 3,783,311 (SATO et al.) 01 January 1974, see Figs. 3-7.	1 and 11-16.

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 MAY 1999	26 MAY 1999

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